Chapter 10 Conclusions

The methods employed in each subtask were profoundly affected by the stimuli presented. The lack of directional cues and spatial organization in the control treatment led to ineffective search strategies and frequent disorientation. The radial grid provided enough information to successfully execute a search but required reinforcing actions to maintain orientation. The map provides a simultaneous geocentric perspective augmenting the egocentric perspective and fostering the use of geographical landmarks and optimizations to search methods. General conclusions drawn from this work include:

1. When not given a source of directional information, disorientation will inhibit both wayfinding performance and spatial knowledge acquisition.
2. A large world with no explicit structure is difficult, if not impossible, to search exhaustively. This was shown by repeated reacquisition behavior in the control treatment.
3. A conceptual coordinate system is often imposed on the world to act as a divider. This is a side-effect of not being able to divide the world explicitly. A structure must be imposed on the world if an organized exhaustive search is to be attempted.
4. Experimental observations support the notion that path following is a natural spatial behavior. Subjects frequently used features such as coastlines or grid lines as if they were paths.
5. A map allows for optimizations to be made to search strategies. This is because it can be considered a supplement to survey knowledge.

6. Dead reckoning was observed to be an intuitive and natural part of navigation; all subjects exhibited this behavior even though frequently unaware of it. The ability to infer position from a past location and constant velocity over time, while sometimes complex in reality, appears to be more easily understood and implemented in virtual spaces.

Each of these relates directly back to the design principles presented in Chapter 5. The results of this research support the validity of the application of real-world environmental design principles to virtual world design. Environmental cues in virtual worlds adapted from real-world principles effect spatial behavior in predictable ways analogous to wayfinding behaviors in the real world.

Contributions

This dissertation is the first significant study of its kind concerning wayfinding in large-scale virtual worlds. The objective of this research was to show that real-world wayfinding and environmental design principles are effective in designing virtual worlds which support skilled wayfinding behavior. The contributions of this work involve the actual principles in the investigation, the behaviors exhibited during task execution, the types of wayfinding tasks, and a taxonomy of spatial characteristics for virtual worlds.

Wayfinding Principles

The principles studied were based first on the psychological foundations of both spatial orientation and cognitive map theory and second, on architectural and environmental design methodology. The principles are divided into two parts; one specific to organizational elements, and one specific to map usage. The organizational principles are:

1. Divide the large world into distinct small parts, preserving a sense of “place”. This should be hierarchical in nature.
2. Organize the small parts under a simple organizational principle.
3. Provide frequent directional cues.

The map principles are:

1. Show organizational elements (paths, landmarks, districts, etc.) and particularly the organizational principle.
2. Always show the observer’s position.
3. Orient the map with respect to the observer such that the forward-up equivalence principle is accommodated.

Wayfinding Tasks

Wayfinding tasks can be generalized into two primary categories; searching and exploring. Searching tasks must have a specific target or goal while exploration tasks do not have a specific goal. However, this is too general to be useful. We need to know enough about why the user is moving to be able to draw some conclusions as to what environmental information is necessary for their success. Therefore, wayfinding tasks have been divided into three primary categories:

1. Naive search: Any searching task in which the navigator has no a priori knowledge of the whereabouts of the target in question. A naive search implies that an exhaustive search is to be performed.
2. Primed search: Any searching task in which the navigator has some prior knowledge of the location of the target. A primed search implies that a non-exhaustive search is to be performed.
3. Exploration: Any other wayfinding task in which there is no target.

Spatial Characteristics

Unlike the physical world, a virtual world can have any shape, be any size, and act any way the designer or builder desires. Consequently, it is important to know what the relevant spatial characteristics are which have an effect on wayfinding design. In most cases, the spatial characteristics are imposed on the environment by the application and therefore constrain the problem (and the solution) of wayfinding. The taxonomy presented here describes virtual space in terms of the following ten factors:

- Scale: Small Large
- Extent: Close/Discrete Far/Infinite

- Detail: Indistinct ⇔ Confounding
- Density: Sparse ⇔ Dense
- Dimension: Planar ⇔ Volumetric
- Distribution: Uniform ⇔ Clustered
- Activity: Static ⇔ Dynamic
- Accessibility: Restricted ⇔ Free
- Occlusion: Obstructed ⇔ Clear
- Organization: Amorphous ⇔ Schematized

Wayfinding Behaviors

Lastly, when wayfinding tasks are executed in an environment either conforming to or violating the wayfinding design principles and having certain spatial characteristics, specific behaviors are exhibited. The general task is broken into subtasks including orientation/position acquisition, reacquisition, and maintenance, search, exploration, and spatial memorization. Behaviors associated with each treatment are described in Chapter 8.

Future Work

Before the wayfinding design principles can be fully utilized by virtual world builders and designers, it is necessary to incorporate them into a design methodology similar to that which exists today for graphical user interface design. The future work items listed in this section are presented in a prioritized list indicating a rough chronological order of importance.

Extend Wayfinding Principles

The experiment described in this dissertation involved worlds which are physically similar to the real world. The reasons for this are discussed in Stimuli and Apparatus on page 104. Although this was a logical approach to take for this first step, the principles will need to be extended to other types of large virtual spaces which are not so similar to the real world. The approach to this work will be similar to that described here; specifically on

the cognitive elements of navigating space. However it will broaden the scope of applicability into the taxonomy of spaces presented in Spatial Characteristics on page 90.

This objective could be achieved by an experiment, similar to this one, which would utilize worlds which were selected to widely sample the spatial characteristic parameters. The major problems with such an approach would be first, in making sure subjects were not confused by the environment and the cues presented, and second, in using enough different worlds to effectively test the principles. Both of these issues would have to be evaluated in pilot studies.

A study of this type could not only verify the applicability of the principles to other types of spaces but could also extend the actual principles themselves. As stated in this thesis, no claim is made that the principles presented here are complete.

Orientation Study

The cognitive elements of navigation are but one third of the problem. Inasmuch as we may attempt to understand this part of the task, if the perceptual and motor issues are not addressed, any design methodology will be ill founded.

There are many aspects of perception which are relevant to wayfinding. Because the world builder is responsible for all stimuli presented to the user, the filtering effect described in Method on page 101 is significant and consequently extremely important. Issues such as visual and aural acuity within head-mounted displays and headphones are not well understood. These all play a part in the larger issue of orientation and the ability of the user to maintain it in virtual space.

Although this topic in general was addressed in this experiment, the perceptual aspects of the problem were assumed to be constant. The fidelity of stimuli between hardware display devices (visual, aural, haptic, or tactile) is significantly different. Consequently, we will need to understand how this difference manifests itself in navigation tasks.

Locomotion Study

Similar to perceptual issues, motor functions have also not been addressed here. The results clearly showed that the locomotion metaphor had an adverse effect on subjects'

ability to navigate. We have anecdotal evidence for why this may have occurred but locomotion in large virtual spaces has been, in general, an overlooked research area.

Mapping a small physical space (usually constrained by the size of the laboratory) to a large virtual space is non-trivial. Not only is efficiency needed for large, coarse movements, but fine control and accuracy is also necessary for small movements. Furthermore, movement techniques should make use of natural human abilities in accordance with the strengths of the technology.

Rather than produce a number of case studies of movement techniques (we already have this), research is needed to determine what the relevant factors are of effective movement styles, how they might change with the spatial characteristics of the world, and if individual differences are significant enough to warrant changing the method on a user to user basis.

Wayfinding Design Methodology

The importance of wayfinding to the usability of a virtual space requires that it be considered during the design phase of development. The methodology outlined by Passini (1984) could be used as a suitable starting point. However, he makes extensive use of the fact that he is designing for a physical space — an invalid assumption in the case of virtual worlds. Consequently, just as the real-world wayfinding principles investigated in this experiment had to be generalized as to their function apart from their form, the same must be done for Passini's design methodology. However, the major points remain valid (See Environmental Design Methodology on page 75).

1. Wayfinding tasks (Travel from A to B; likely points of departure and destination. This is more specific than the search/explore tasks described earlier.)
2. User profile (Expert users? Novice users?)
3. Wayfinding conditions (How critical is success? Is the user in a hurry?)
4. Design requirements (Triads of tasks, users, and conditions)
5. Wayfinding solutions (Predict what navigation behavior is expected)

6. Supportive information (To achieve the expected behavior, what added information is needed? This is where the wayfinding principles apply.)
7. Design solution (The actual form of the supportive information - also known as navigation aids - is described in detail.)

Miscellany

Another issue relevant to navigating virtual worlds is that of navigating through time. This can be thought of as wayfinding in four-space. In the case of a simulation over time in which the user must control the direction of flow and rate of time passage, this is yet another dimension in which to become disoriented. Do the principles extend to this problem? Can time be represented in such a way as to make the principles apply? This topic would have to be made the subject of an extensive formative study in order to understand its relevant issues.

Lastly, a topic of growing interest is that of autonomous agents. An agent could be used to assist users of a virtual world in locating specific points of interest. In some respects, this would limit the importance of designing for wayfinding. However, it opens new questions as to how the user will interact with such an agent, what the agent is capable of doing, and how the environment must be built to enable agent navigation. In most cases, it would seem that even if navigation agents are to be used, the world must still be designed for the human as well. This is particularly true for exploratory behavior which has no specific focus.